SAND 80-2406
UNLIMITED RELEASE

MASTER

OIL SHALE PROGRAM
EIGHTEENTH QUARTERLY REPORT
APRIL 1980 THROUGH JUNE 1980

EDITED BY A. L. STEVENS

Prepared by Sandia Laboratories, Albuquerque, New Mexico 87185
and Livermore, California 94550 for the United States Department of
Energy under Contract DE-AC04-76DP00789.

PRINTED NOVEMBER 1980

Sandia National Laboratories

R145

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

Issued by Sandia National Laboratories, operated for the United States Department of Energy by Sandia Corporation.

NOTICE: This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government, any agency thereof or any of their contractors or subcontractors. The views and opinions expressed herein do not necessarily state or reflect those of the United States Government, any agency thereof or any of their contractors or subcontractors.

Printed in the United States of America

Available from

National Technical Information Service
U. S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

Price: Printed Copy \$4.50
Microfiche \$3.00

CATEGORY NO. UC91

SAND 80-2406
Unlimited Release
Printed November 1980

OIL SHALE PROGRAM
EIGHTEENTH QUARTERLY REPORT
APRIL 1980 THROUGH JUNE 1980

Edited by
A. L. Stevens
In Situ Technologies
Sandia National Laboratories
Albuquerque, New Mexico 87185

DISCLAIMER

This book was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

INTENTIONALLY LEFT BLANK

TABLE OF CONTENTS

	<u>PAGE</u>
INTRODUCTION AND SUMMARY	1
A. GEOKINETICS OIL SHALE PROJECT (R. L. Parrish, 4737)	5
1. FORMATION EVALUATION (C. E. Tyner, 4734; P. M. Drozda, R. D. Jacobson, R. L. Parrish, 4737)	5
B. OCCIDENTAL OIL SHALE PROJECT (R. R. Neel, 4737)	12
C. ANALYTICAL EVALUATION OF GEOKINETICS RETORT BLASTING (J. T. Schamaun, 4734)	14
D. FRACTURE AND FRAGMENTATION STUDIES ON OIL SHALE (D. E. Grady, L. S. Costin, 5532)	15
E. EVALUATION OF FAILURE SURFACE MODEL (L. S. Costin, 5532)	17
F. MINIMUM BED PARAMETERS FOR IN SITU PROCESSING OF OIL SHALE (C. E. Tyner, 4734)	18

INTENTIONALLY LEFT BLANK

INTRODUCTION AND SUMMARY

This report describes the Sandia National Laboratories oil shale activities during the period between April 1, 1980, and June 30, 1980. Sandia serves a dual role in the DOE Fossil Energy in situ oil shale program:

- (1) Provide a quantitative evaluation to DOE of field projects being supported by DOE/FE in the development of commercial in situ oil shale processes, and
- (2) Conduct in-house research to address key limiting technological problems and develop analytical techniques, diagnostic tools, and hardware to support the evaluation mission.

Currently, instrumentation and evaluation activities are in progress at two DOE-supported in situ oil shale field projects, namely, the Geokinetics Oil Shale Project near Vernal, Utah, and the Occidental Oil Shale Project near DeBeque, Colorado. In support of these projects, it is necessary to develop new and advanced instrumentation systems and associated deployment, recording and analysis techniques that are unique to the field project needs. A rock mechanics program provides material properties, material response models and computational methods for use in the design analysis, and evaluation functions. In addition, retorting studies are in progress on problems unique to the low void conditions encountered in field experiments. This project describes detailed activities in these project areas over the last quarter.

Geokinetics Oil Shale Project - Air flow and tracer tests were conducted this quarter on previously-rubbed Retorts 21, 22, and 23. These tests were conducted to determine (1) the overall void and permeability distributions of these retorts and (2) the comparative suitability for retorting. Retort 22 has been tentatively selected for a joint Geokinetics/Sandia retorting experiment.

The airflow/tracer test results, like those reported previously for Retort 19, showed that a substantial amount of air flow typically entered the detector well above the retort zone proper (i.e., through the overburden). Unlike Retort 19, where the flow through the retort

zone was in the upper half of the rubbled zone, in Retorts 21, 22, and 23 the flow was generally distributed throughout the retort zone. Detailed results are given in graphic and tabular form. Average void fractions calculated from the tracer results were 14, 7, and 10 percent for Retorts 21, 22, and 23, respectively. This agrees well with the residual surface heave.

The question of whether or not the toe charges detonated in Retort 23 was not resolved. In general, the flow extended to the bottom of the explosive column. However, in one well the flow extended below the explosive column, but not down to the level of the toe charge.

Analytical Evaluation of Geokinetics Retort Blasting - Modeling studies were conducted to evaluate the overburden behavior during the blasting of Retort 24. The study was primarily aimed at determining the critical areas of overburden distortion (binding and shearing) and associated energy loss mechanisms. Such distortions create loss paths for subsequent retorting gases.

The effects of explosive load factors and detonation timing were included for the typical Geokinetics retort blasting configuration which uses initiation rounds followed by sequential "walking W" scheme. Based on the correlation of these model results with Retort blast 24, recommendations were offered for the blast of Retort 25 which would reduce the overburden heave and distortion by reducing the quantity of explosive load factor used and changing the detonation timing and detonator locations within the explosive column. The blast of Retort 25 is scheduled for next quarter.

Occidental Oil Shale Project - During the quarter, the MR-3 Fragmentation Test was conducted at the Logan Wash facility. Sandia fielded several rock mass (mine stability) instruments to determine their response to the close-in effects of the rubblization blast. Extensometers, stressmeters, and rubble pressure gages were fielded and data were recorded before, during and after the blast. The results were reviewed at the DOE/Oxy project review meeting in June. A written report is in preparation.

Preparations for the MR-3 Start-Up Test are in progress. An array of thermocouples will be placed at various depths in the rubbled zone from a grid of holes around the burner. The ignition of MR-3 is expected

in September 1980. The instrumentation for MR-4 Start-Up is expected to be very similar to that used on MR-3 and is being processed accordingly.

Preliminary planning for the intra-retort and process monitoring instrumentation on Retorts 7 and 8 continues. The layout of surface facilities has been defined by Occidental and provides space for the Sandia data acquisition trailer B-61.

A multi-channel multi-gas tracer system is being assembled for use in evaluating the retort rubble permeability distribution.

Fracture and Fragmentation Studies on Oil Shale - The dependence of dynamic fracture strength and fragment size distribution on strain rate has previously been established. Current work is aimed at characterizing the dependence of dynamic fragmentation properties on oil shale grade. Particle size distributions were determined through sieving analyses of the fragmented rock resulting from changing oil shale grade under otherwise fixed loading conditions. The results were found to depend sensitively on kerogen content. Further analysis determined the energy dissipated during dynamic fragmentation and established a quantitative index of fracture resistance as a function of oil shale grade. The technique affords an immediate comparison with quasi-static fracture toughness data.

Minimum Bed Parameters for In Situ Processing of Oil Shale - Two laboratory retort runs (numbers 028 and 029) were completed this quarter using cylindrical samples with longitudinal slices. The void ratio for the two samples were 16 and 7 percent, respectively. These void ratios are at the lower end of the range that may be realized in non-uniform rubbing of large field retorts. The samples were well instrumented and retorted using air. Material balance calculations, using real-time off gas analysis results along with other experimental data, indicate the fraction of the total amount of oil shale that was retorted (sweep efficiency), and the losses due to combustion and coking. Correlations are being made with measured off-gas alkene/alkane ratios.

INTENTIONALLY LEFT BLANK

OIL SHALE PROGRAMS
EIGHTEENTH QUARTERLY REPORT

A. Geokinetics Oil Shale Project (R. L. Parrish, 4737)

Sandia is participating in the Geokinetics Oil Shale Project through design and fielding of instrumentation, acquisition and interpretation of data, and predictive modeling. These activities are directed toward increased understanding and improvements in the Geokinetics true in situ process while developing a technical base which will be applicable to other oil shale projects. Previous activities have included instrumentation and analyses of the fracturing phase of Retorts 17 through 24, formation assessment via airflow and tracer tests of Retort 19, and retort modeling. Activities this quarter consisted of airflow and tracer tests on Retorts 21, 22 and 23.

1. Formation Evaluation (C. E. Tyner, 4734; P. M. Drozda, R. D. Jacobson, R. L. Parrish, 4737)

As aforementioned, airflow and Krypton-85 tracer tests were conducted this quarter on Retorts 21, 22 and 23. These sites had been rubblized as part of a special series of fracturing tests; the tracer tests were for (1) overall formation evaluation and (2) to determine the comparative suitability for retorting. Final selection of the site for the Sandia conducted retorting experiment (tentatively Retort 22) will be made in part from the results of these tests.

A description of the tracer system and data acquisition and analysis techniques were included in last quarters report⁽¹⁾ together with a summary of the results of the tracer tests on Retort 19. These tests were conducted in much the same manner. The significant difference was that, in lieu of special wells drilled for the tracer tests, the retort injection (air-in) wells were used as the injection wells and the observation and/or liquid production (pump) wells as the detector wells. The injection (AI) wells were cased to within 10 ft. of the bottom of the retort interval; airflow and tracer were thus injected into the forma-

1. Oil Shale Programs Seventeenth Quarterly Report, January 1980 through March 1980, A. L. Stevens, Ed., SAND 80-1470, July 1980.

tion from the 10 ft. open wellbore interval. The liquid production (PW) wells had solid casing to the top of the retort zone, then slotted casing to the bottom of the well. The observation (OB) wells had 20 ft. of solid casing from the earth surface part way through the overburden, with slotted casing to the well bottom. Plan views of the three retort sites are shown in Figure A-1, together with the wells used in the tests and the spacing between injection and detection wells.

Figures A-2 through A-4 provide summaries of the tests by well pairs. The percentage of recovered airflow, percentage of total void, and total void volume are presented as a function of depth. Schematics depicting the solid and slotted portions of the casings in the detection wells, and the retort and overburden regions are also shown.

The test results, like those for Retort 19, showed that a substantial amount of the airflow typically entered the detector well above the retort zone proper (i.e., above the powder column). Unlike Retort 19, where the remainder of the flow was through the upper half of the retort interval, airflow was generally found throughout the retort interval. Regions of high flow and high void generally corresponded, probably meaning roughly equivalent rubbleization in the permeable regions. The void distribution in the various regions tested is summarized in Table A-I. Assuming that, for a given well pair, the flow was confined to a region between those wells (i.e., a circle with diameter equal to the well spacing except for AI to PW-2 well pair tests where the entire retort area was used) the average total "height" of the void and the void fraction was determined. This average "height" was about 4.6 ft. in Retort 21, 2.3 ft. in Retort 22, and 3.2 ft. in Retort 23. Average void fractions, based on a 30 ft. retort interval (powder column plus residual lift in the retort zone) were 14, 7, and 10 percent for Retorts 21, 22, and 23, respectively.

Some observations made during the conduction of the tests that may well have influenced the results should be included in an overall evaluation. In particular, the results obtained on any one test could be highly wellbore dependent. The observation and production wells are drilled through the rubble, then the thin-wall slotted casings are emplaced with a pushing rotary motion that is conducive to local buckling of the casing and/or plugging up the perforations. If and when this occurs, the airflow into that well may flow up the well outside the

FIGURE A-1. PLAN VIEWS OF RETORTS 21, 22, and 23. WELLS LABELED AI-1 OR AI-2 WERE THE TRACER INJECTION WELLS. WELLS LABELED PW OR OB WERE THE TRACER DETECTION WELLS. ARROWS DENOTE THE AIRFLOW DIRECTION AND THE DISTANCE BETWEEN INJECTION AND DETECTION WELLS IS NOTED.

FIGURE A-2.

FIGURE A-3.

FIGURE A-4.

TABLE A-1
CALCULATED TOTAL "VOID HEIGHT" AND VOID FRACTION
IN TESTED ZONES, GKI RETORTS 21, 22 and 23

	<u>SPACING</u> (ft)	<u>AREAL FLOW EXTENT (1)</u> (ft ³)	<u>TOTAL CALC. VOID (2)</u> (ft ³)	<u>VOID HEIGHT</u> (ft)	<u>VOID FRACTION (3)</u> (%)
Retort 21					
A11-PW1	36.6	1,052	4,352	4.1	12
A11-OB2	49.7	1,463	8,928	4.8	14
A11-PW2	80.3	3,200	15,634	4.9	14
Retort 22					
A11-PW1A	45.7	1,640	5,221	3.2	10
A11-OB2	61.0	2,922	4,194	1.4	5
A11-PW2	100.3	5,000	11,571	2.3	7
Retort 23					
A12-PU1	45.8	1,647	6,016	3.6	11
A12-OB1	30.8	745	1,581	2.1	7
A12-PW2	99.4	5,000	20,330	4.1	12

(1) Assumes flow confined to circle with diameter equal to well springs except AI-PW2 test which use retort area.

(2) From tracer tests.

(3) Based on 30' powder column.

casing for some undetermined distance before entering the casing and passing by a detector. This, in turn, would result in apparent zero or low flow at these depths when in fact the airflow distribution is quite uniform. This could account for the zero flow increments from AI-1 to PW-1 on Retort 21 and from AI-2 to OB-1 on Retort 22. A post-test TV log of Well PW-1A on Retort 22 revealed that the casing was damaged (caved in) at and possibly also below the 42 ft. depth; no flow into the well was found below the 51 ft. depth. The water level was found to have influenced the lower limit of airflow in some tests; the measured water level is noted. The use of wells fully cased from the surface to the top of the retort interval obscured the airflow distribution in the overburden; in these tests only the total percentage of airflow in the overburden could be ascertained.

Finally, the question as to whether the toe charges on Retort 23 had detonated was not resolved. The airflow into Well PW-1 was only to the bottom of the powder column. The airflow into Well OB-1 extended below the powder column, but not down to the toe charge. Testing was suspended before the tests from AI-2 to PW-2 were completed; the airflow distribution into this well was not obtained.

B. Occidental Oil Shale Project (R. R. Neel, 4737)

During the quarter, the MR-3 Fragmentation Test was conducted in the research mine. Final preparations were undertaken for the MR-3 Start-Up Test scheduled for September, 1980. Preliminary planning for the thermal and process monitoring instrumentation on Retorts 7 and 8 continues. The layout of the surface facilities has been defined by Occidental and construction of these facilities is under way. Space will be provided for a Sandia office trailer (B-15) and the data recording trailer (B-61). Thermocouples for MR-4 were ordered. Discussions concerning the list of thermocouples for Retorts 7 and 8 thermometry measurements were conducted.

MR-3 Fragmentation Test

The MR-3 Fragmentation Test was conducted on April 28, 1980. The response of typical mine stability instrumentation to the close-in effects of the rubblization blast was recorded during and after the blast. The instrumentation used⁽¹⁾ included wire extensometers, strain gage element inclusion type stressmeters, and large liquid filled rubble pressure gages. The data recorded was reviewed at the June, 1980 Department of Energy Project review meeting. The formal data report is in preparation and is expected to be published in August, 1980.

The following is a summary of the response of these gages.

Extensometers - The extensometer anchors remained in place enabling deformation in the sill pillar and the side pillars to be recorded through the blast. The side pillar extensometers were located within 10 ft. of the outer line of blast holes. Anchors in an angle hole pointing at the shot holes and terminating a few (2-3) feet from one shot hole appeared to have been dislodged affecting the displacement indications. Mine water degraded the electrical output of the extensometers in the angle hole.

Stressmeters - Of the two stressmeters (one radial, one tangential) placed about 10 ft. from the outer row of shot holes, one appeared to operate very well sensing a change in radial stress of about 2800 psi. The second gage experienced electrical failure before the shot.

Rubble Pressure Gages - Two wall and two floor mounted rubble pressure gages sensed vertical (floor) and horizontal (wall) pressure generated by the rubble volume settling on the floor of the retort. A fast recording system recorded the prompt pulse generated as the rubble pile struck the floor of the retort. A low sampling rate, long term recording system observed the long term lithostatic pressure change existing before and after the shot. Although the prompt pulse appears to be appropriate, the change in lithostatic pressure recorded indicates some bridging above the gage resulting in about half the pressure as would have been theorized.

MR-3 Start-Up

The preparations for the MR-3 Start-Up Test are reaching firm configuration. Approximately 115 thermocouples will be placed at various depths in a grid of holes around the burner. Because of the difficulty in keeping scanners and voltmeters operating in the uncontrolled, down-hole, mine environment, the decision was made to cable the MR-3 thermocouples and process monitoring instrumentation directly to trailer B-61 at the mine portal. The cost trade-off between downhole maintenance manpower for MR-3 and MR-4 start-up tests and the cable and cabling manpower was about even. The ignition of MR-3 Start-Up is expected in September, 1980.

MR-4 Start-Up

The instrumentation for the MR-4 Start-Up Test is expected to be very similar to that used on MR-3 and was ordered accordingly. There are indications that MR-4 Start-Up will be accelerated to take place early in November, 1980.

Retorts 7 and 8

Considerable discussions were held concerning the trade-off on Retorts 7 and 8 between hardwire cabling each downhole sensor to the recording trailer at the surface. The effect of the downhole mine environment of downhole multiplexing equipment was the motivating factor for this trade-off. It was once again concluded that larger numbers of surface-to-mine level conductors would be more costly and difficult to install than providing downhole equipment environmental protection.

An alternative thermocouple placement scheme using difficult-to-drill upslant holes was explored by Sandia and Occidental. Up-slant holes are expensive because of the additional hole length required, but they tend to insure the survival of the conductors between the junction and the retort boundary as the retort front sweeps down through the rubble bed. Additional patterns will be explored until a fairly fixed, final pattern is agreed to in July so that thermocouple material must be ordered. As much as 100,000 to 150,000 feet (25 miles) of sheathed thermocouple wire is expected to be needed.

The decision was made for Sandia not to be involved in measuring explosive timing and performance data during the fragmentation of Retorts 7, 8, and 8X.

Rubble Evaluation

Most of the hardware required for a 10 channel demonstration, gas sampling system was procured and assembly commenced. The small trailer needed to house the system is not expected to be available until July.

Program Funding

A program funding crisis caused the manpower, travel, and material procurement for the program to be severely curtailed during May and June. The impact will be to reduce the time available to preparation for the Start-Up tests and make it difficult to change greatly or expand our activities on these tests.

C. Analytical Evaluation of Geokinetics Retort Blasting

(J. T. Schamaun, 4734)

The retort rubblization using the Geokinetics blasting schemes is highly dependent upon the overburden motion. This motion is also very important in defining the resulting overburden permeabilities which directly relate to the amount of retort gas lost to the surface.

Two studies have been completed which provide information about overburden behavior during blasting of Retort 24. 1) A parametric analytical study using the lumped mass program IJUMP was completed. The effects of amount of explosive and timing were included. 2) The test data from a typical walking "W" blasting scheme (optical data from Retort 24) was used to study the effects of overburden distortion and energy absorption. This study was primarily aimed at determining the critical areas of maximum energy losses and maximum overburden distortion.

From these studies, conclusions were drawn which were considered in the blast design for Retort 25. Some of the more significant conclusions are:

1. A reduction in explosive in the initiation round of Retort 25 will provide better overburden motion and retort rubblization.
2. Slight changes in the timing sequence will probably give more uniform heave.
3. The energy losses due to overburden distortion are 5 to 10 times as large as the energy converted into vertical overburden motion in Retort 24.
4. Blast design, timing and quantity of explosive, should be adjusted to minimize both overburden energy losses and fallback values.

D. Fracture and Fragmentation Studies on Oil Shale (D. E. Grady, L. S. Costin, 5532)

Current computational fracture models are based on experimental fracture stress and fragmentation data for nominal 80 ml/kg (20 gal/ton) oil shale. Both quasi-static loading and fracture toughness studies indicate significant variations in fracture characteristics with kerogen content.

An experimental effort which was undertaken to better characterize the dynamic fragmentation properties of various grades of oil shale has been described earlier. In that work 16 tests on solid cylinders of 4 grades of oil shale were fragmented with a torsion split Hopkinson bar apparatus under fixed loading conditions. Particle size distributions were determined through sieving analysis of the fragmented rock and found to depend sensitively on the kerogen content.

During the past quarter, efforts have focused on determining the energy dissipated during dynamic fragmentation and in establishing a quantitative index of the relative fracture resistance of the various oil shale grades. The ratio of the energy expended to the fracture surface area created during the event was selected as the most direct measure of dynamic fracture resistance and provides an immediate comparison with quasi-static fracture toughness data.

An analytic method was selected to determine the fracture surface area created. The method is due to Gaudin and is based on the assumption of a power law size distribution relation--a form which is in good agreement with the sieving analysis results. The energy dissipated was evaluated from the time-resolved strain gage records obtained in the Hopkinson bar tests. The fracture energy/area dependence on oil shale density is shown in Figure D-1 and compared with quasi-static fracture toughness data.

FIGURE D-1.

The fracture toughness data were taken from several sources.⁽²⁻⁴⁾ The fracture energy was determined from fracture tests in which the crack was oriented in the divider geometry (crack front perpendicular to the bedding). For the data of Costin⁽²⁾ and Cleary⁽³⁾ the energy/area was taken to be the critical value of the J-integral (J_{IC}), whereas for the data of Schmidt⁽⁴⁾, the energy/area was computed from the fracture toughness (K_{IC}) using Irwin's relation.

The Hopkinson bar fracture energy/area results in Figure D-1 indicate a minimum resistance to fracture at the higher densities or, equivalently the lower kerogen content specimens. There also appears to be a dramatic increase in fracture resistance with increasing kerogen content initiating at about 2.1 to 2.2 mg/m³ and increasing to about three times the minimum value at the highest kerogen content material studied (160 ml/kg). This break in material property behavior at about 100 ml/kg is reminiscent of ultrasonic studies on oil shale. The dynamic fracture efficiency is about a factor of five lower than the quasi-static strain energy release rate. The trend of the quasi-static data is also towards increasing fracture resistance with increasing kerogen content although apparently not as dramatic as the dynamic data.

Continued work will focus on achieving a better understanding to the relationship between the dynamic and the quasi-static fracture results and in correlating this body of data with earlier strain-rate dependent fragmentation studies. The objective will be to obtain improved computer model material properties consistent with the range of kerogen contents expected in the field.

E. Evaluation of Failure Surface Model (L. S. Costin, 5532)

The failure surface model which is currently being used in code calculations of pillar and roof strengths for the Occidental retort design was developed by T. Priddy (5522) for orthotropic composite materials. In the past quarter, an experimental program was begun to evaluate the applicability of this model to oil shale. To this end,

2. Costin, L. S., "Static and Dynamic Fracture Behavior of Oil Shale," Proceedings of the ASTM Symposium on Fracture Mechanics Methods for Ceramics, Rocks, and Concrete, Chicago, IL, June 1980.
3. Cleary, M., "Some Deformation and Fracture Characteristics of Oil Shale," Proceedings of the 19th U.S. Rock Mechanics Symposium, Stateline, NV, May 1978.
4. Schmidt, R. A., "Fracture Mechanics of Oil Shale," Fourth Quarterly Oil Shale Report, SAND 77-0196, March 1977.

samples of oil shale were procured from the Occidental Oil Shale Company's mine at Logan Wash, Colorado and from the Anvil Points mine near Rifle, Colorado. Uniaxial tension and compression tests as well as triaxial tests are being conducted on specimens of these two shales. These tests will be sufficient to define the failure surface for a single grade of oil shale. Once the failure surface is defined, biaxial tests (compression-torsion) will be conducted and the results compared to the model's predictions.

F. Minimum Bed Parameters for In Situ Processing of Oil Shale

(C. E. Tyner, 4734)

Retort Runs

Retort runs 028 and 029 were completed this quarter using sliced cylinder samples similar to that used in Run 027 (see second quarterly report).⁽⁵⁾ Sample voids for the two runs were 16 and 7%, respectively. Figure F-1 shows the sample geometry schematically, while Figure F-2 is a photo of an actual assembled sample (top view).

The Retort 028 sample was a 26.6 gpt 7.6 cm by 26 cm long cylinder with three 0.64 cm slices removed axially. The core was reassembled, instrumented, and the slices (voids) filled with $-.32 + .16$ cm 40.5 gpt rubble. Overall sample void was 16%.

The sample was retorted using air at a flow rate of 3 slm (flux of $0.017 \text{ kg}_{\text{air}}/\text{m}_{\text{sh}}^2 \cdot \text{sec}$), 60% of the flow used in Retort 027. Ignition was similar to Retort 027, with exit oxygen dropping to about 2% by 0.3 hrs. into the run and remaining at approximately that value for the entire run.

The retorting front moved at a velocity of 4.5 cm/hr (1.1 m/day) with a heating rate in the retorting zone of $8^\circ\text{C}/\text{min}$. Peak temperatures were about 700°C , considerably lower than in Retort 027, and probably indicating more heat loss (as could be expected at the lower flow rate). Temperature profiles at a number of locations along the bed centerline in the rubble are shown in Figure F-3. Figure F-4 shows a number of temperature profiles and 6 and 18 cm into the sample. At 6 cm, for example, the plot shows temperatures in the rubble (0) peaking first,

5. C. E. Tyner, "Minimum Bed Parameters for In Situ Processing of Oil Shale," Second Quarterly Report, January 1 through March 31, 1980, Sandia National Laboratories Report SAND 80-1455, June 1980.

FIGURE F-1. SLICED-CYLINDER GEOMETRY.

FIGURE F-2. SAMPLE 027, ASSEMBLED (TOP VIEW).

RUBBLE TEMPERATURES
RETORT RUN 028 05/06/80

FIGURE F-3.

6,18 CM DEPTH TEMPERATURES
RETORT RUN 028 05/06/80

FIGURE F-4.

followed by the block surface (14), and finally, by the block center (10). Figure F-5 shows plots of rubble temperature versus distance down the bed at several points in time. Steady movement of the thermal wave through the bed is evident. Figures F-6 and F-7 show, respectively, experimental flow rates and exit oxygen concentration and inlet pressure.

FIGURE F-5.

FIGURE F-6.

EXIT OXYGEN & INLET PRESSURE
RETORT RUN 028 05/06/80

FIGURE F-7.

Measured yield (based on density determination of shale grade) was 82%, somewhat lower than the 95% measured for Retort 027. Probable causes for the decreased yield were the lower heating rate (and hence increased coking) and higher heat losses. Predicted yield based on the real-time gas analyses was about 70%, using both a material balance calculation and the LLNL correlation of off-gas alkene/alkane ratios. This discrepancy is being investigated.

The retort run 029 sample was similar to that described above, except that rubble regions were only 0.32 cm (1/8") thick and filled with -.16 +.08 cm (+1/16 -1/32 in.) rubble. Overall sample void was approximately 7%. We are not aware of any previous attempts to retort at this low a void in a controlled laboratory environment.

The sample was retorted using air at a flow rate of 5 slm. Ignition was similar to previous runs. Except for a brief excursion of the exit oxygen concentration at 5% late in the experiment, retorting proceeded in a fashion similar to previous runs. (The exit oxygen was brought down to a level of 2.5--and decreasing--by the end of the experiment by increasing the total flow to 7 slm.) Retort pressure drop (see Figure F-8) was not significantly higher than previous experiments, indicating that retorting at 7% void is feasible, at least under the conditions of this experiment.

EXIT OXYGEN & INLET PRESSURE RETORT RUN 029 06/25/80

FIGURE F-8.

Temperature profiles (comparable to those shown in Figures F-3 to F-5 for run 028) are shown in Figures F-9 to F-11 for run 029. One interesting difference (most evident in Figure F-10) is the early rubble temperature peak (probably caused by gas phase combustion of oil and

RUBBLE TEMPERATURES RETORT RUN 029 06/25/80

FIGURE F-9.

6,18 cm DEPTH TEMPERATURES
RETORT RUN 029 06/25/80

FIGURE F-10.

CENTERLINE TEMPERATURE PROFILES
RETORT RUN 029 06/25/80

FIGURE F-11.

product gas), followed by a slight dip and then a broad char combustion peak. The product combustion peak was not evident in the block temperatures (10 or 14). Figure F-12 shows inlet and outlet flow rates for run 029.

Material balance calculations made using real time off-gas analysis results were very interesting. The calculations estimated that 2307 g of shale (94% of the total charge of 2462 g) were retorted, while 15% of Fischer Assay oil was combusted, leaving 190 g of oil (84% FA) available for production. Actual yield was 168 g of oil (75% FA). Calculations for the period when the exit oxygen concentration was high indicate the retorting rate had dropped to about half of its previous level, and nearly one quarter of the oil generated was being combusted.

Analysis of the data from these two runs is continuing. Results will be reported when completed.

FIGURE F-12.

Retort Analysis and Model Comparisons

Retort run 027 (the geometry of which was identical to that of run 028, while the process air flow was 5 slm [flux of $0.029 \text{ kg}_{\text{air}}/\text{m}_{\text{sh}}^2 \cdot \text{sec}$]) was completed in February, 1980, and raw data from this experiment were presented in the second quarterly report.⁽⁵⁾ Retort model calculations have since been made using Sandia's block retorting code and actual

experimental parameters--flow, block size and grade, etc. A comparison of these results with experimental temperature profiles and the recently determined char boundary location is discussed below.

Figure F-13 shows typical temperature profiles (of block surface temperatures) versus time at several locations in the retort bed (6, 12 and 18 cm from the top). The results of model calculations at these locations are shown as solid lines for comparison. Figure F-14 shows similar results of temperature versus distance down the bed centerline at two different times (1.0 and 2.0 hrs. into the experiment). Model

BLOCK SURFACE TEMPERATURES

RETORT RUN 027 02/29/80

FIGURE F-13.

CENTERLINE TEMPERATURES

RETORT RUN 027 02/29/80

FIGURE F-14.

calculations are again shown as solid lines. Finally, Figure F-15 shows an experiment-model comparison of the difference between block wall and block center temperatures (i.e., thermal gradient through the block) at 12 cm into the bed as a function of time.

Agreement between measured and calculated temperatures is surprisingly good, considering such things as the rubble (not considered in model) heat loss in the experiment, etc. Comparison of retorting rate, local heating rate in the retorting zone, yield, and extent of char combustion were also very good. Measured retorting retorts varied from 9.5 cm/hr in the top half of the retort to 8.9 cm in the bottom half. Calculated values were 10.3 and 10.0 cm/hr. Measured heating rate varied from 29.2°C/hr to 14.8°C/hr over the retort, while calculated values

FIGURE F-15. DIFFERENCE BETWEEN BLOCK SURFACE AND CENTER TEMPERATURES - RETORT RUN 027

ranged from 20.5 to 16.2°C/hr. Measured yield (based on a density determination of Fischer Assay) was 95% of Fischer Assay. The calculated yield for the blocks was 91.3% (7.9% loss to combustion, 0.8% to coking). Assuming a yield for the rubble of nearly 100% (probably a good assumption under the experimental conditions), the overall calculated yield would be 92.8% FA. These results are summarized in Table F-1.

Figure F-16 shows calculated and experimental positions of the char boundary, i.e., the boundary between the shrinking core of retorted but unburned shale and the burned shale. The experimental char boundary location was determined by axially sectioning the retorted sample perpendicular to the rubble zones and measuring the distant boundary in the two inner blocks. Figure F-17 is a photograph of the sectioned sample. Agreement is reasonably good, although the calculated boundary is somewhat steeper than that observed.

While the results of this single experiment are insufficient to verify the many aspects of the block retort model, they are encouraging. Further comparisons to investigate the effects of block size and grade, void fraction, and gas flux and composition will be made as experiments are completed and data analyzed.

TABLE F-1.
COMPARISON OF CALCULATED AND MEASURED RESULTS
FROM BLOCK RETORTING RUN 027

		<u>Top of Retort (6-12 cm)</u>	<u>Bottom of Retort (12-18 cm)</u>
Retorting Rate (cm/hr)	Measured	9.5	8.9
	Calculated	10.3	10.0
Heating Rate (°C/hr)	Measured	29.2	14.8
	Calculated	20.5	16.2
			<u>Total</u>
Yield (%FA)	Measured		95
	Calculated		92.8

Other Activities

Other activities completed during the quarter included installation and initial use of a data acquisition computer system and a gas chromatograph, and development of a calculator program to perform oil shale material balance calculations rapidly without use of a computer.

Installation of the ModComp Modacs III computer system was completed early in the quarter, and software development advanced rapidly enough that the system was used on Retort 029. The system currently accepts data (thermal, flow, pressure, etc.) from a datalogger, stores the data on disks, and outputs the data to a HP printer and plotter for display. Software for direct plotting and printing is being developed as manpower allows.

A Hewlett-Packard gas chromatograph for retort off-gas analysis was also brought on-line during the quarter. Sample turn-around time for a complete gas analysis through C₄'s is 30 minutes. For shorter retort runs, bomb samples are also taken at the 15 minute points between real time samples for post-run analysis.

One reason for requiring real-time off-gas data is to allow use of that data in analyzing progress of the retort--in real time. The material

FIGURE F-16. RETORT RUN 027 - CHAR BOUNDARY LOCATION

balance scheme developed by Hommert⁽⁶⁾ can, for example, use the data to determine rates of retorting, oil combustion, carborate decomposition, etc. One criticism of the material balance calculation has been that it requires a computer. While the general availability of computers at most oil shale retorting experiments somewhat invalidates this criticism, the need for a quick, convenient, non-computer scheme for solving the material balance equations (which involves a 9×9 matrix inversion)

6. P. J. Hommert, "Material Balance Calculations for True In Situ Oil Shale Retorting," 12th Oil Shale Symposium Proceedings, Colorado School of Mines, April 1979.

FIGURE F-17.

does exist. A program capable of running on an HP41C hand-held calculator has been developed for this purpose. Fully prompted data input (gas compositions, total flow, shale grade, etc.) requires about one minute, while execution of the program to yield the amounts of shale retorted and oil produced, the percentages of oil burned and carbonates decomposed, etc., requires an additional four minutes. The calculator routine has been used to analyze gas data from Retorts 027, 028, and 029. Results agree exactly with those obtained from computer runs.

DISTRIBUTION:

TIC-4500-UC91 (168 copies)

George Fumich, Jr.
Assistant Secretary
for Fossil Energy
Mail Stop B-126
Washington, DC 20545

Office of Deputy Assistant Secretary
for Oil, Gas, & Shale Technology (10)
U. S. Department of Energy
Mail Stop D-107

Washington, DC 20545

Attn: M. Adams
B. Harney
J. W. Ramsey
A. M. Hartstein
J. R. Smith
P. R. Wieber
H. E. Thomas
E. L. Burwell
R. W. Markley
D. Uthis

U. S. Department of Energy
Division of Planning & Systems Engr.
Room C-164

Washington, DC 20545

Attn: J. T. Bartis, Acting Director

Laramie Energy Technology Center (8)

P.O. Box 3395, University Station

Laramie, WY 82071

Attn: R. J. Jiacoletti
J. H. Weber
W. E. Little
B. C. Suddeth
L. P. Jackson
D. R. Johnson
A. E. Harak
R. E. Poulson

Los Alamos Scientific Laboratory (5)

Los Alamos, NM 87545

Attn: W. J. Carter, DAD/AES, MS 329

W. A. Morris, G-4, MS 586
J. N. Johnson, T-4, MS 214
C. L. Edwards, G-2, MS 978
T. S. Adams, G-6, MS 665

Lawrence Livermore Laboratory

P.O. Box 808

Livermore, CA 94550

Attn: A. E. Lewis

Science Applications, Inc.

1546 Cole Blvd.

Suite 210

Golden, CO 80401

Attn: H. E. McCarthy
G. B. French

Keith Britton
Blastmasters, Inc.
325 Beverly Avenue
San Leandro, CA 94577

U. S. Bureau of Mines - Twin Cities
P.O. Box 1660
Twin Cities Airport, MN 55111
Attn: Richard Thill
Sam Demou

Rio Blanco Oil Shale Co.
9725 E. Hampden Avenue
Denver, CO 80231
Attn: J. Knepper

Science Applications, Inc.
P.O. Box 273
Steamboat Springs, CO 80477
Attn: C. Young

Occidental Oil Shale, Inc. (9)
751 Horizon Drive
Box 2687

Grand Junction, CO 81501

Attn: W. McDermott
R. Ellington
R. Nelson
J. Feinman
G. Gruber
R. Bloom
T. Ricketts
B. Romig
W. Karwoski

J. Virgona

U.S. Department of Energy
Laramie Energy Technology Center
2784 Crossroads Blvd.

Rm. 110

Grand Junction, CO 81501

Equity Oil Company

10 W. Third South

Suite 806

Salt Lake City, UT 84101

Attn: P. M. Dougan

Geokinetics, Inc.

288 Buchanan Field Rd.

Concord, CA 94520

Attn: M. Lekas

Geokinetics, Inc.

c/o 582 N. Vernal Avenue

Vernal, UT 84078

Attn: J. Lekas

DISTRIBUTION (cont.):

U.S. Department of Interior (2)
Area Oil Shale Office
131 North 6th, Suite 300
Grand Junction, CO 81501
Attn: P. Rutledge
L. Barker

Rocky Mountain Energy Co.
Lakeside National Bank Bldg.
4707 Harlan Street
Denver, CO 81501
Attn: T. I. Sharps

5000 J. K. Galt
5100 F. L. Vook
5500 O. E. Jones
5510 D. B. Hayes
5520 T. B. Lane
5521 R. K. Thomas
5530 W. Herrmann
5532 B. M. Butcher
5541 W. C. Luth
8266 E. A. Aas
3141 T. L. Werner (5)
3151 W. L. Garner (3)

The Aerospace Corporation
2350 East El Segundo Blvd.
El Segundo, CA 90009
Attn: G. F. Kuncir

Carbondale Mining Technology Center
Department of Energy
P.O. Box 2587
Carbondale, IL 62901
Attn: T. Ziegler

1 M. Sparks
2 W. J. Howard
400 C. Winter
1000 G. A. Fowler
1100 C. D. Broyles
1110 J. D. Plimpton
1116 R. P. Reed
1120 T. L. Pace (3)
Attn: B. C. Benjamin, 1123
G. L. Ogle, 1125
1130 H. E. Viney
2510 D. H. Anderson
2514 P. J. Langdon
3151 A. A. McConnell
4000 A. Narath
4523 J. F. Ney
4536 R. D. Klett
4700 J. H. Scott
4710 G. E. Brandvold
4720 V. L. Dugan
4730 H. M. Stoller
4731 B. Granoff
4732 D. A. Northrop
4733 C. L. Schuster
4733 L. K. Warno
4734 A. L. Stevens (10)
4734 R. R. Boade
4734 J. T. Schamaun
4737 B. E. Bader
4737 R. L. Parrish
4737 R. R. Neel
4741 S. G. Varnado
4742 A. F. Veneruso